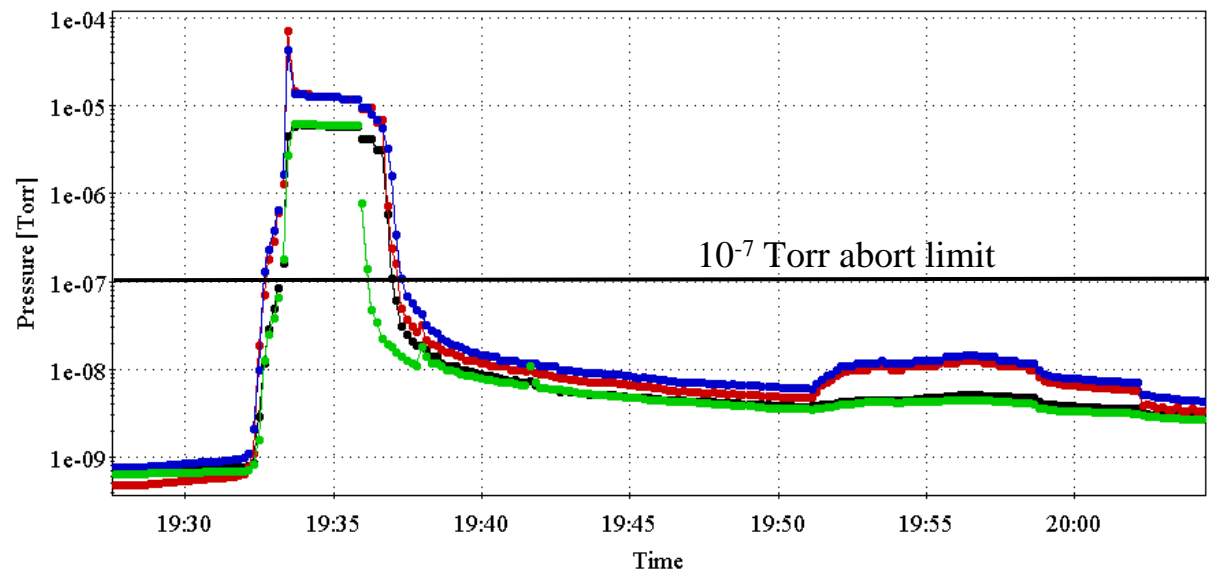
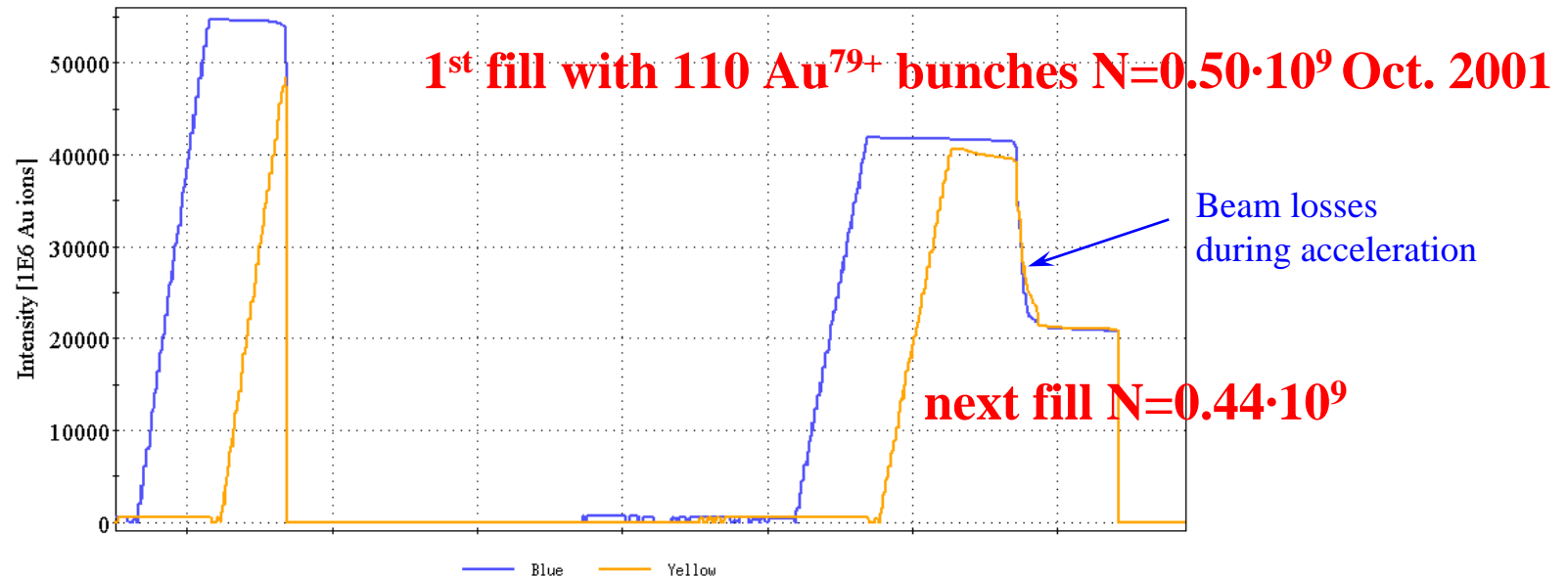


RHIC vacuum limitations

Wolfram Fischer

1. Pressure rise observations
injection – transition – store
2. Pressure instabilities
3. Counter measures



	Au ⁷⁹⁺	d ⁺	p ⁺
Pressure rise locations	only warm		warm / cold
Injection			
Pressure rise observed	Yes	Yes	Yes
E-clouds observed directly	Yes	Yes	Yes
Transition			
Pressure rise observed	Yes	Yes	N/A
E-clouds observed directly	Yes with large losses	No	N/A
Store			
Pressure rise observed	Yes	No	No no rebucketing
E-clouds observed directly	No	No	No

Pressure rise observed Yes = pressure rise ≥ 1 decade

E-clouds observed directly = observed with electron detector

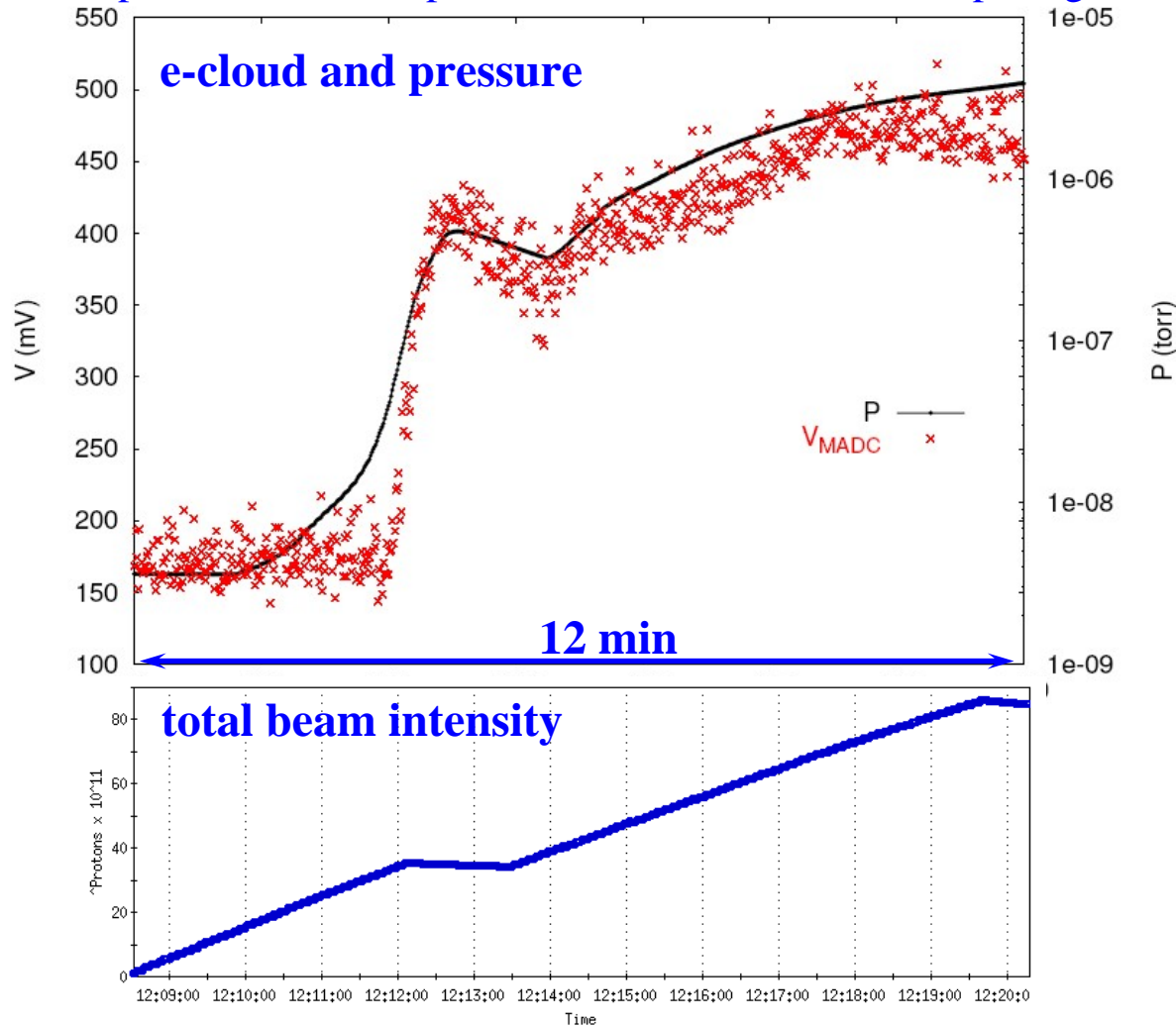
Pressure rise mechanisms considered so far

- Electron cloud → **dominating for operational problems**
 - Coherent tune shift in bunch train
 - Electron detectors
- Ion desorption → **tolerable for operation**
 - Rest gas ionization, acceleration through beam
 - Ion energies $\sim 15\text{eV}$ for Au, $\sim 60\text{eV}$ for p
 - Visible pressure rise, may lead to instability in conjunction with electron clouds (Au only)
- Beam loss induced desorption → **tolerable for operation**
 - Need large beam loss for significant pressure rise
 - New desorption measurements in 2004
(H. Huang, S.Y. Zhang, U. Iriso, and others)

Electron cloud and pressure rise

$86 \cdot 10^{11}$ p⁺ total, $0.78 \cdot 10^{11}$ p⁺/bunch, 110 bunches, 108 ns spacing

U. Iriso-Ariz

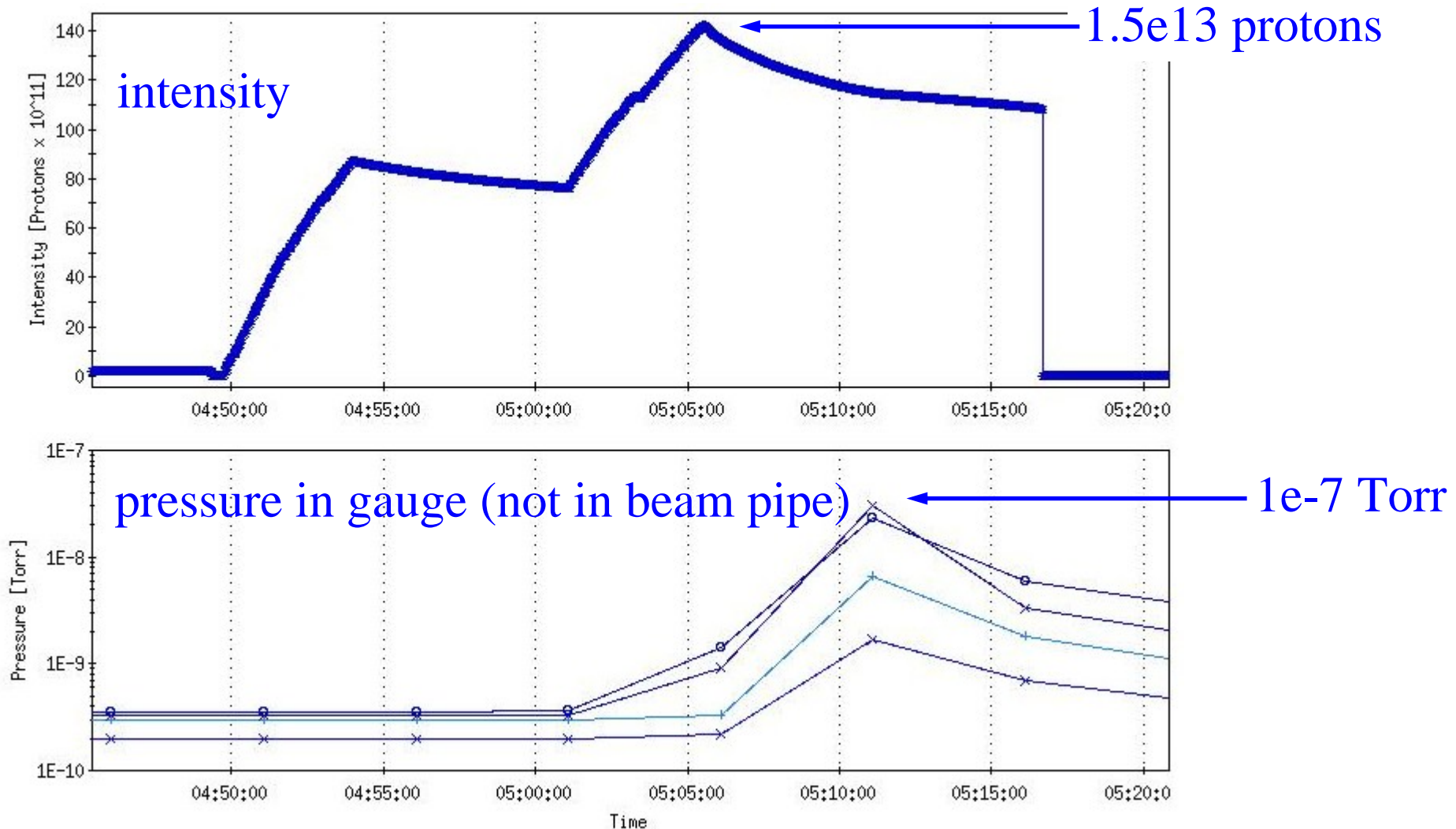


**Clear connection
between e-cloud
and pressure at
injection**

**Estimate for η_e
assuming pressure
caused by e-cloud:
0.001-0.02**
(large error from
multiple sources)

[U. Iriso-Ariz et al. "Electron cloud observations at RHIC in Run-3", BNL C-A/AP/129 (2003).]

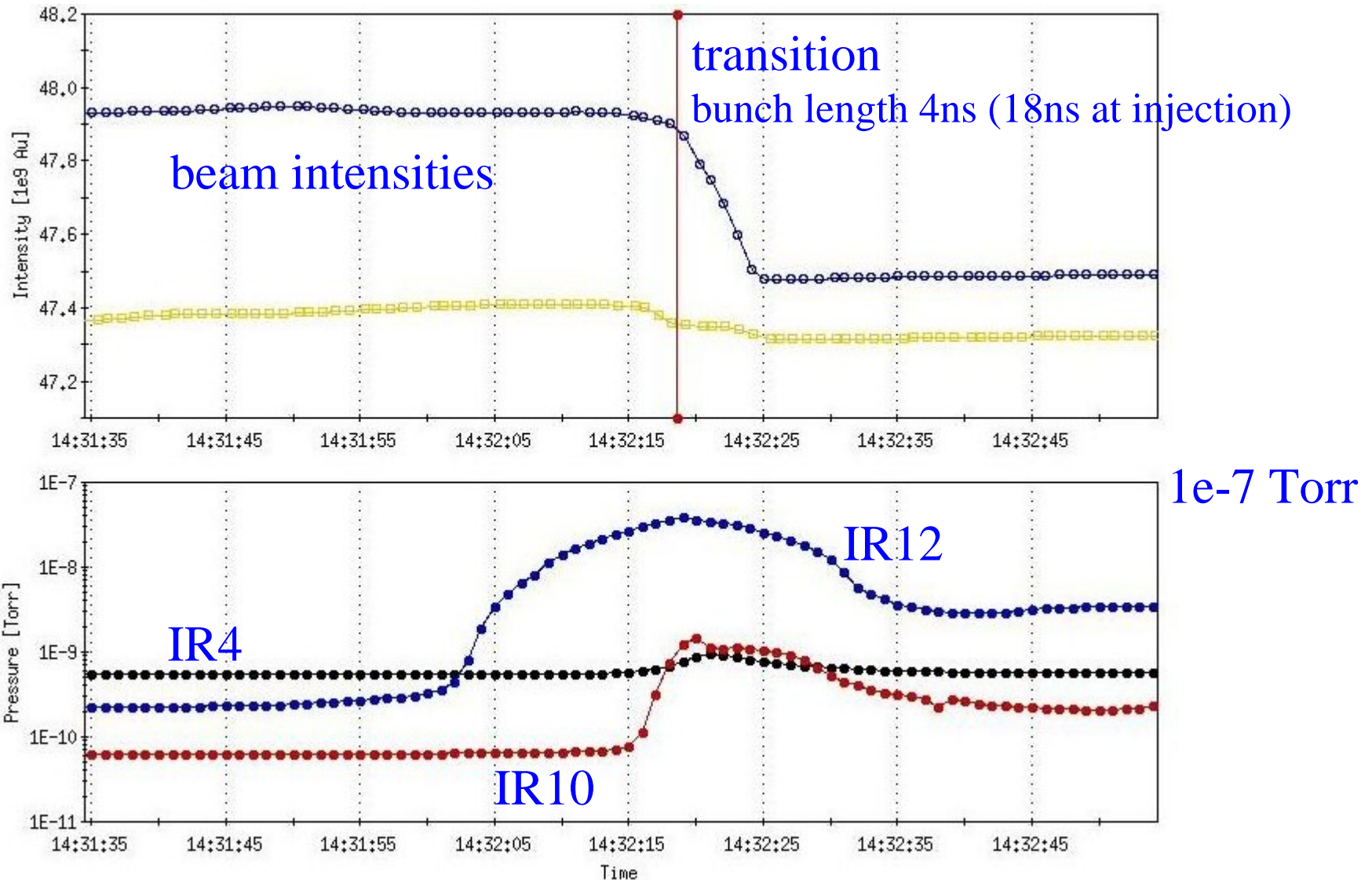
Gas density increase observed in cold regions with intense proton beams



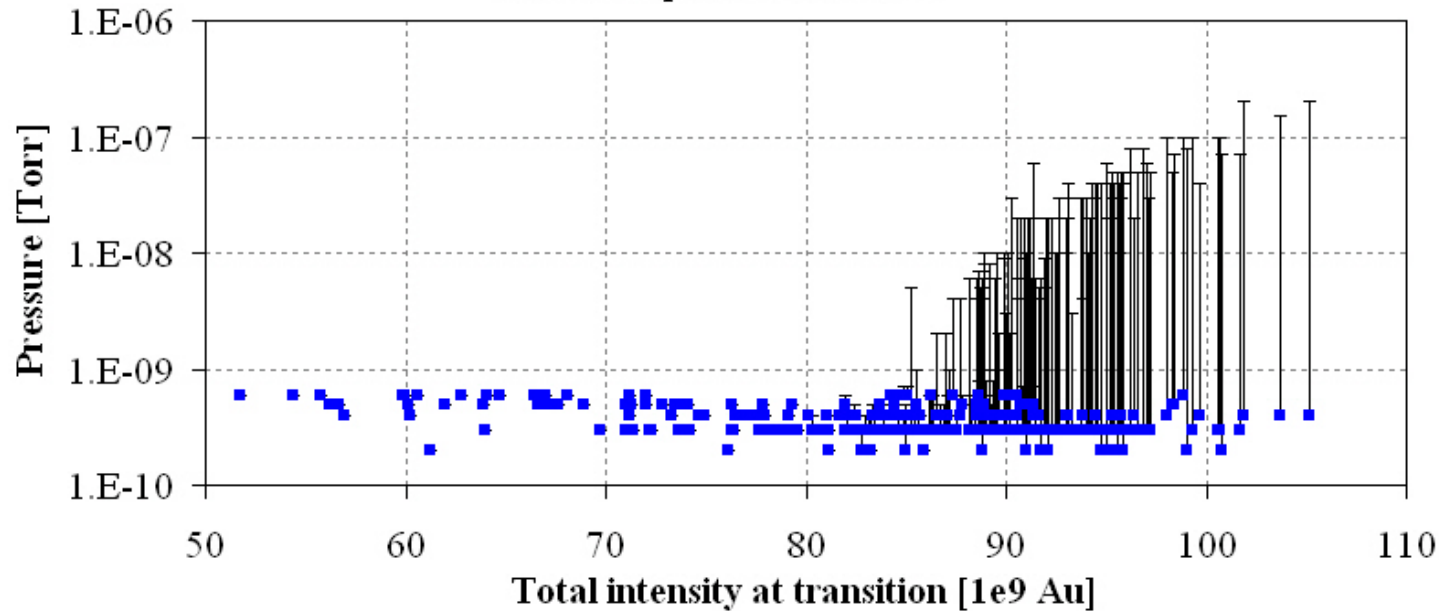
Cold surface not very clean (acceptable so far):

- Pressure when cool-down starts: $1\text{e-}1$ Torr
(in almost all cold regions in the past)
→ About 10 mono-layers after cool-down
- Pumping 500m arcs with turbo for 2 weeks: $1\text{e-}3$ Torr
(10 days after stop pumping: $1\text{e-}2$ Torr)
- Need to install more turbo pumps
→ $1\text{e-}3$ Torr initial pressure results in 0.1 mono-layer

Typical transition pressure rise in Au-Au operation



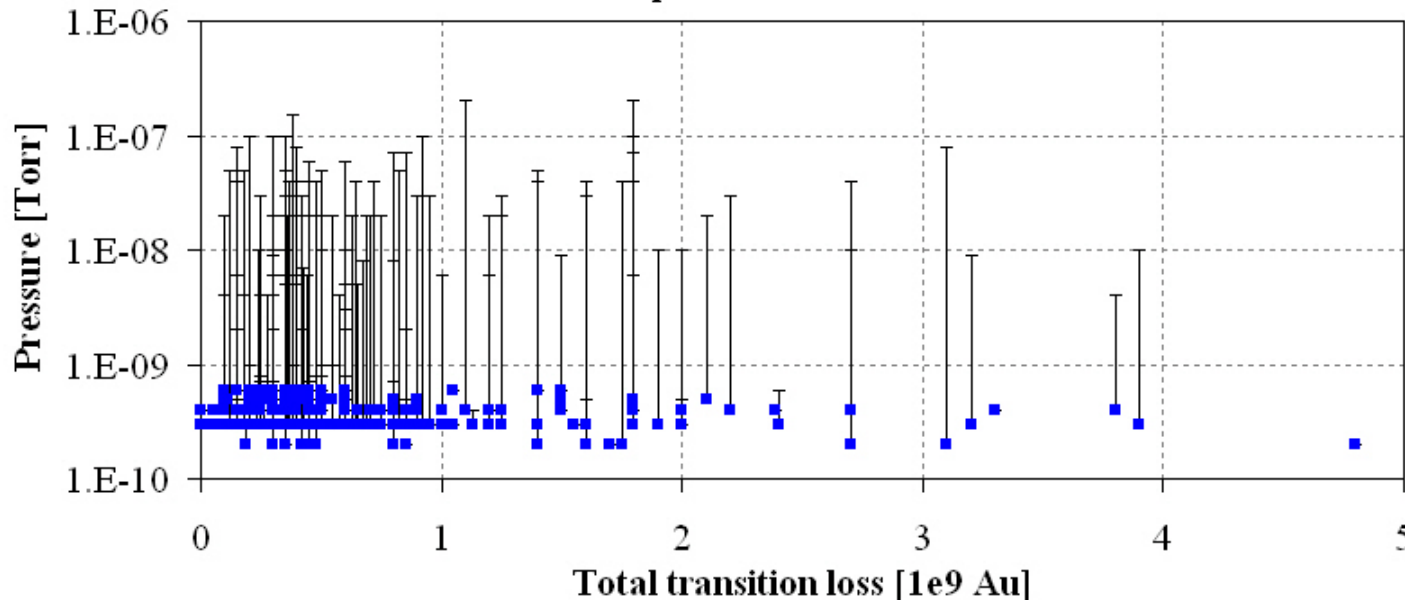
Transition pressure rise IR12



Pressure rise at transition

Strongly
intensity
dependent

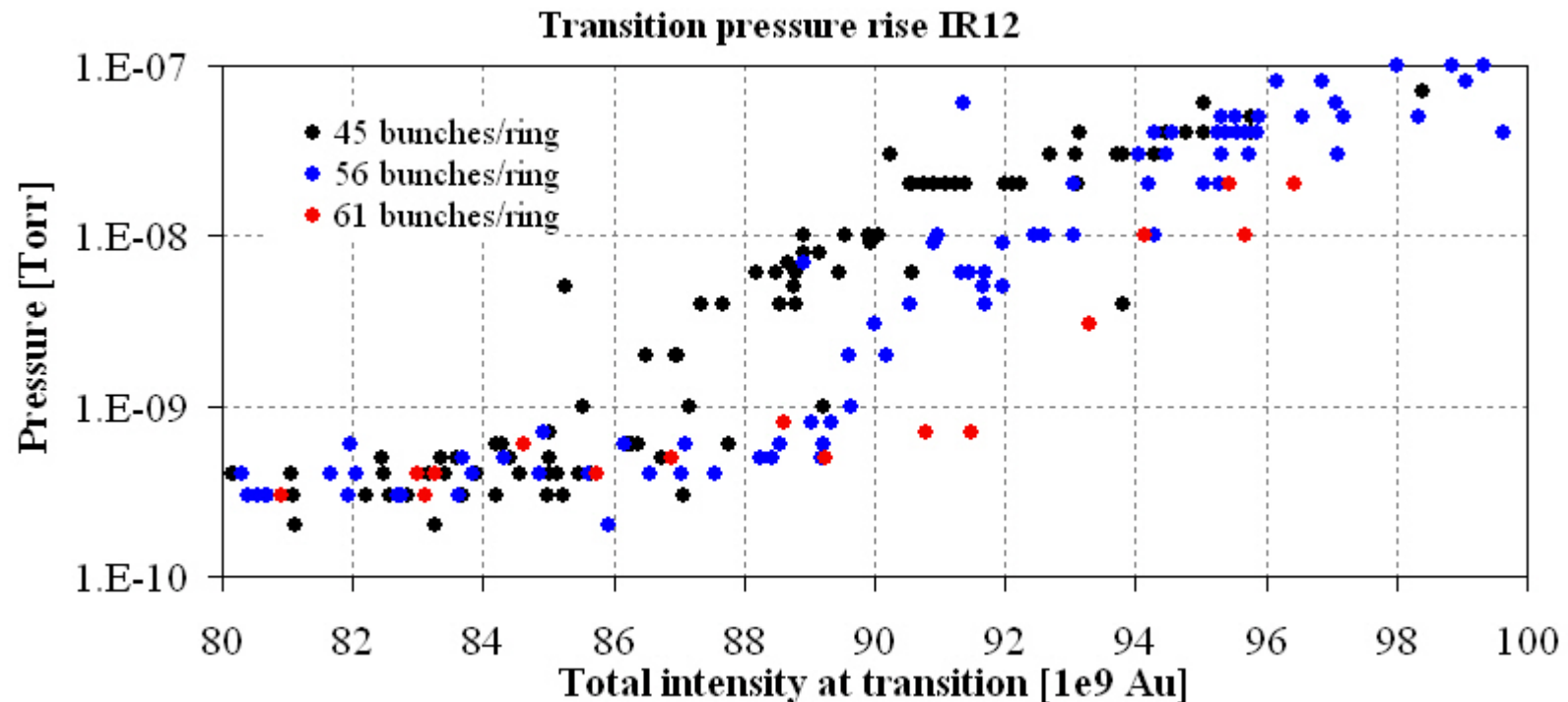
Transition pressure rise IR12



No correlation
with beam loss

→ suggests
electron clouds

Stronger pressure rise for fewer bunches in IR12
(independent of pattern in IR10 – same as Run-3, S.Y. Zhang)



→ Behavior can be qualitatively reproduced in e-cloud simulation (U. Iriso)

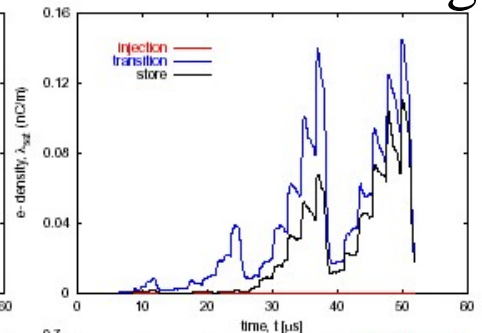
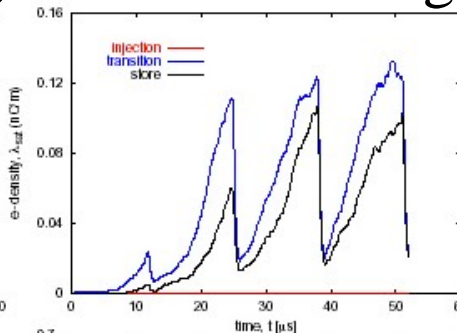
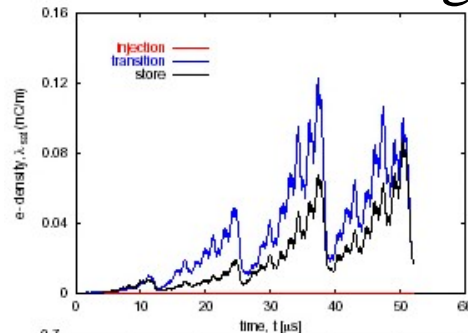
With fewer bunches, cloud density and current into wall is reduced, but electron impact energy is increased, and can lead to larger desorption. (simulation by U. Iriso)

e-cloud density

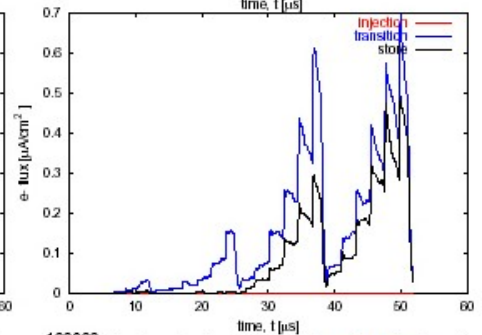
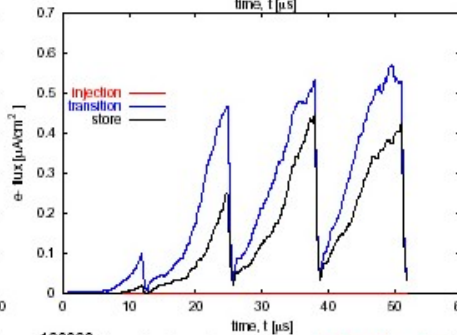
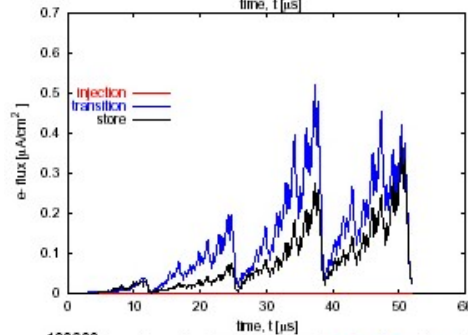
45 bunches/ring

56 bunches/ring

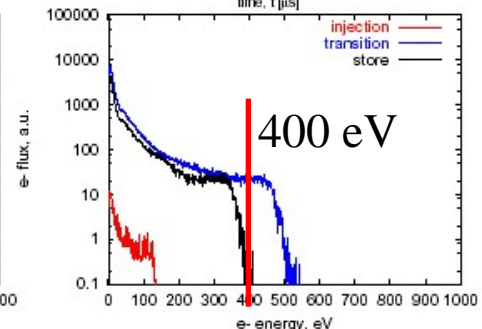
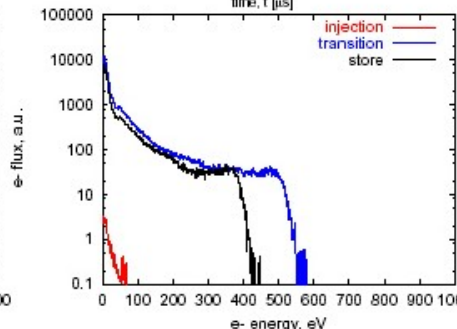
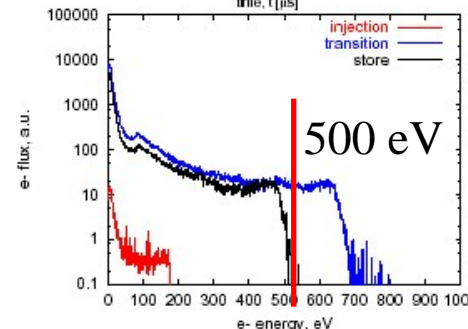
61 bunches/ring



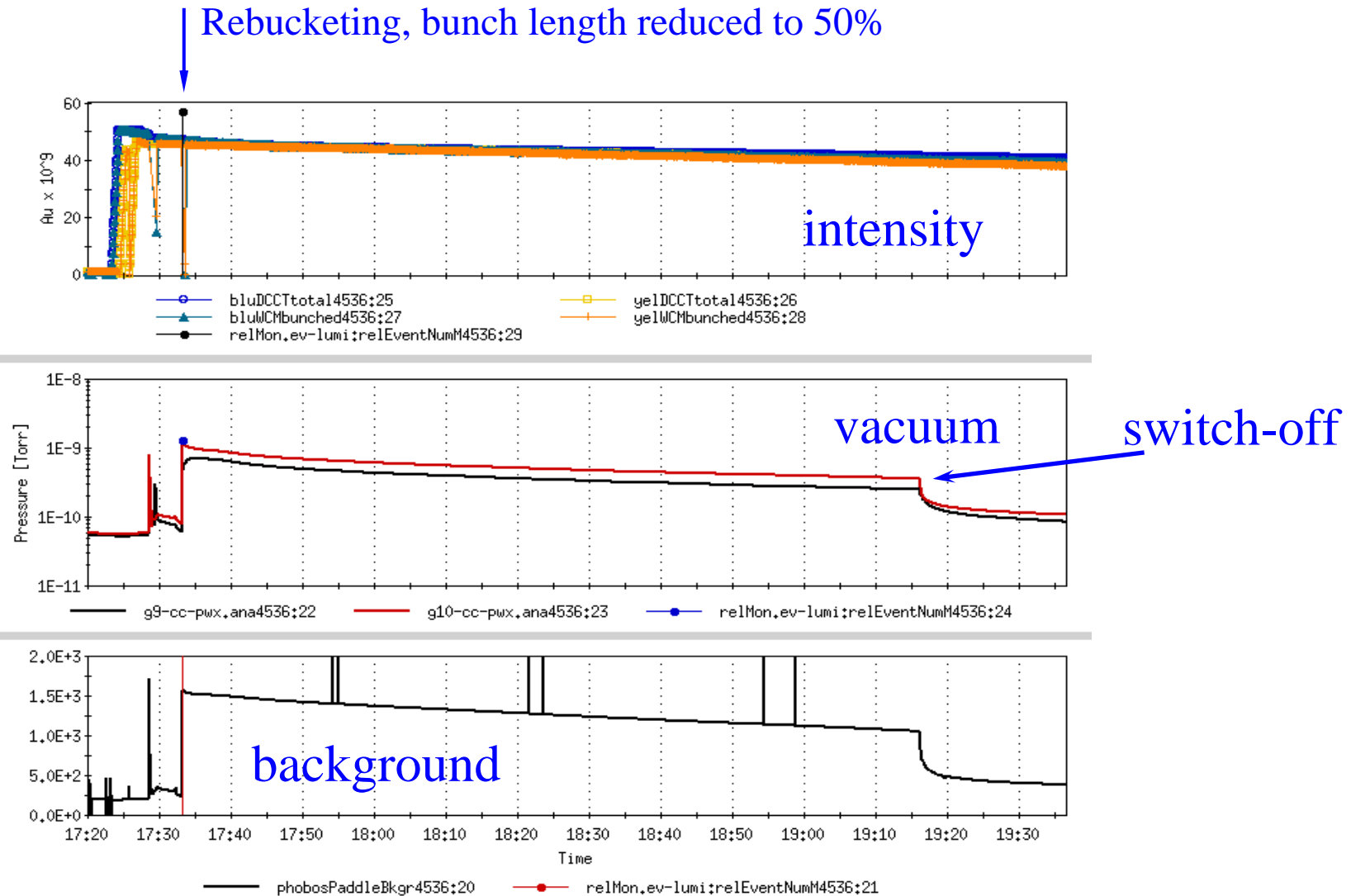
current into wall



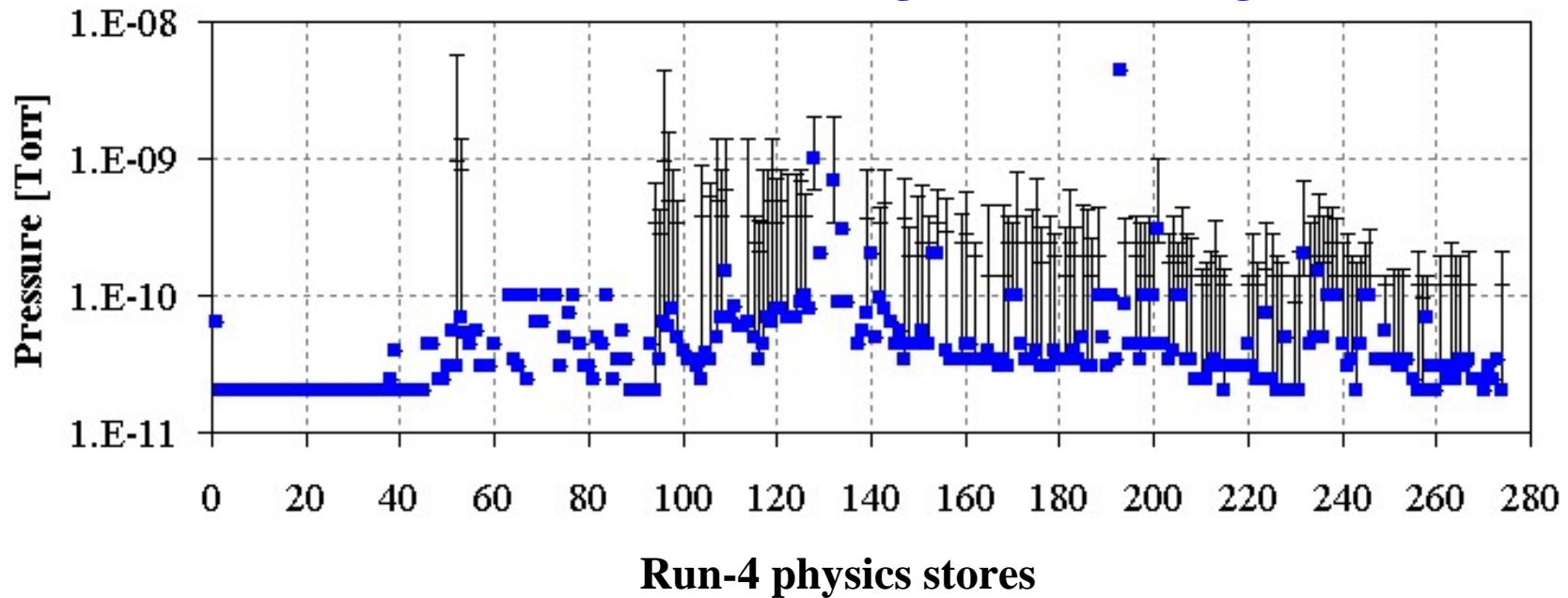
electron impact energy



PHOBOS background increase after rebucketing, drops after minutes to 2 hours
(most severe luminosity limit in Run-4)



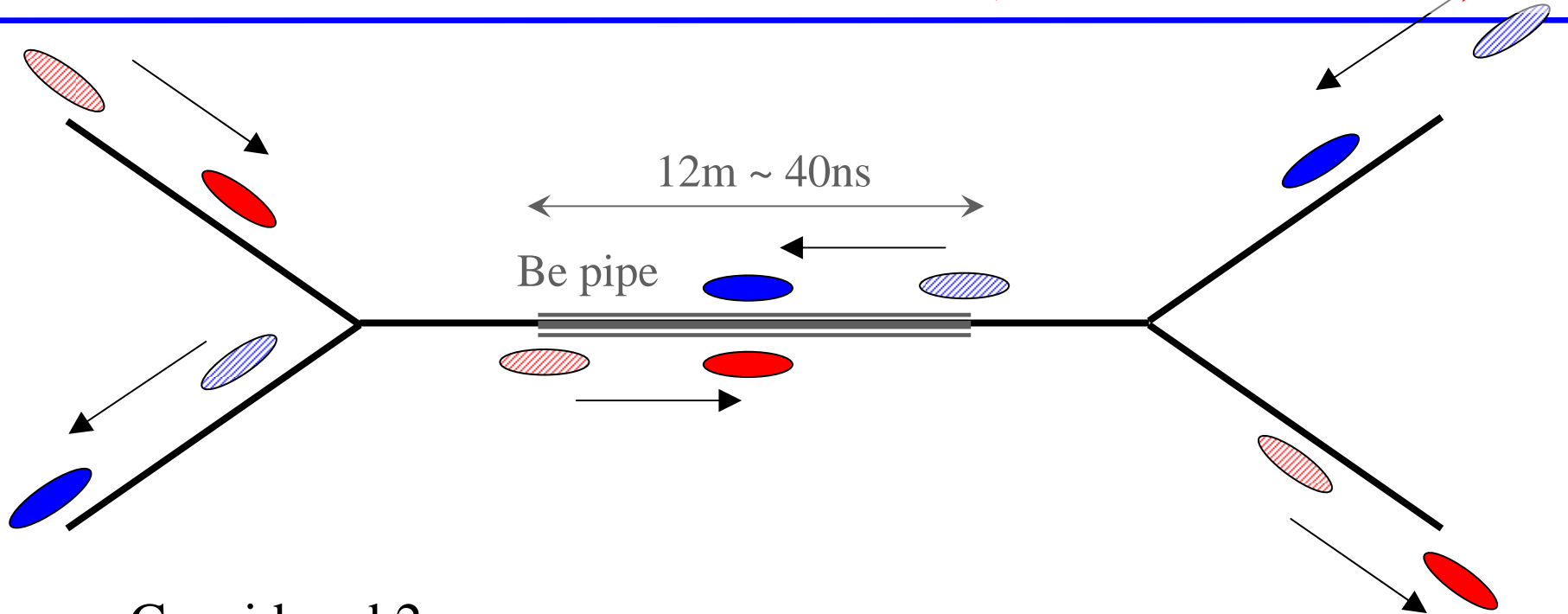
Pressure before and after rebucketing (50% bunch length reduction)



Did not find narrow range that triggers problem for

- average bunch intensity
- peak bunch intensity
- pressure before rebucketing

No good correlation with any parameter and duration either



Considered 2 cases:

At IP:

nominal bunch spacing ($\sim 216\text{ns}$) and double intensity

At end of the beryllium pipe:

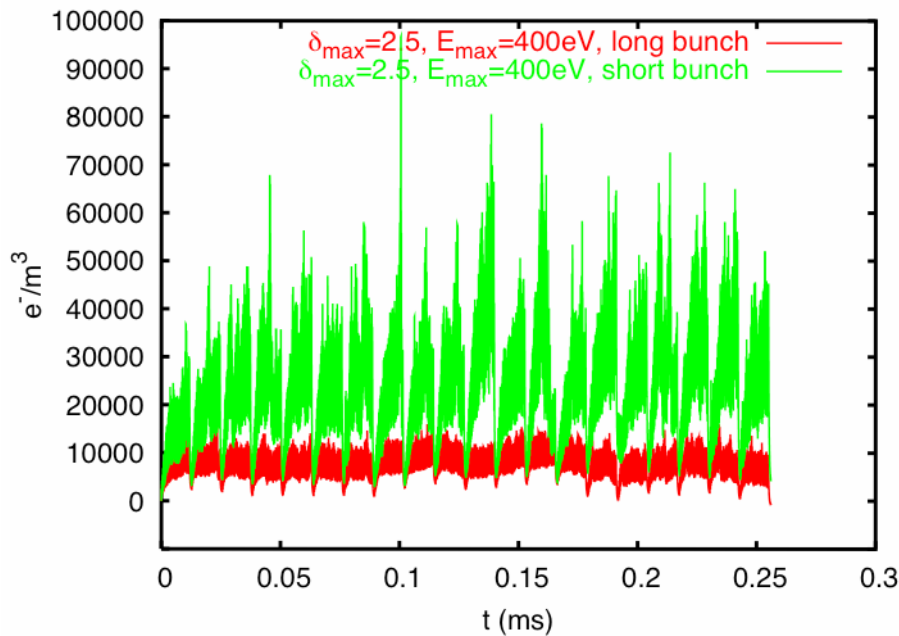
normal intensity, spacing of 40ns then 176ns

[G. Rumolo and W. Fischer, "Observation on background in PHOBOS and related electron cloud simulations", BNL C-A/AP/146 (2004).]

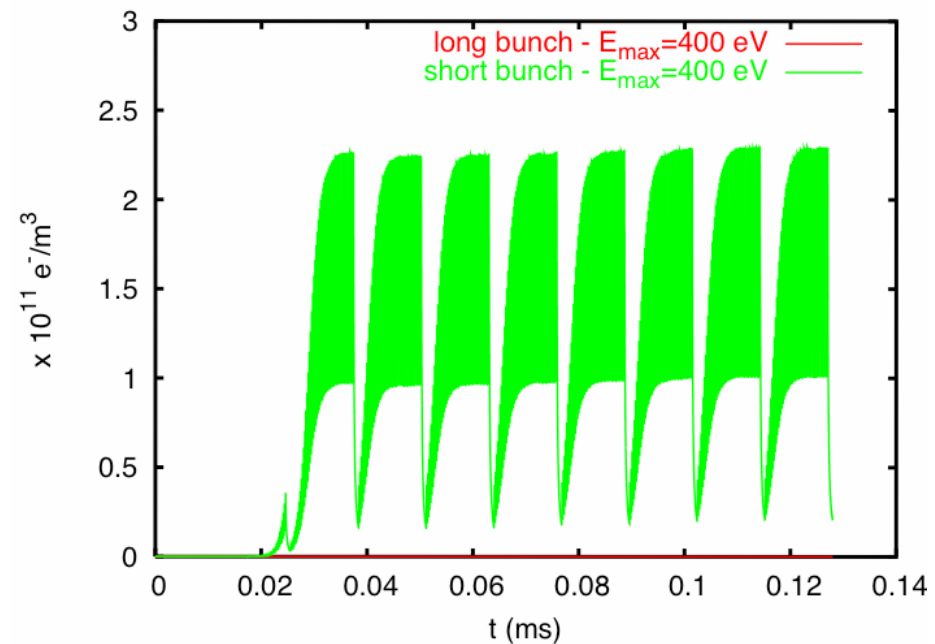
Important result:

After surface parameter calibration find e-clouds
at end of 12m Be pipe, but not in center
→ May be sufficient to suppress e-cloud at ends

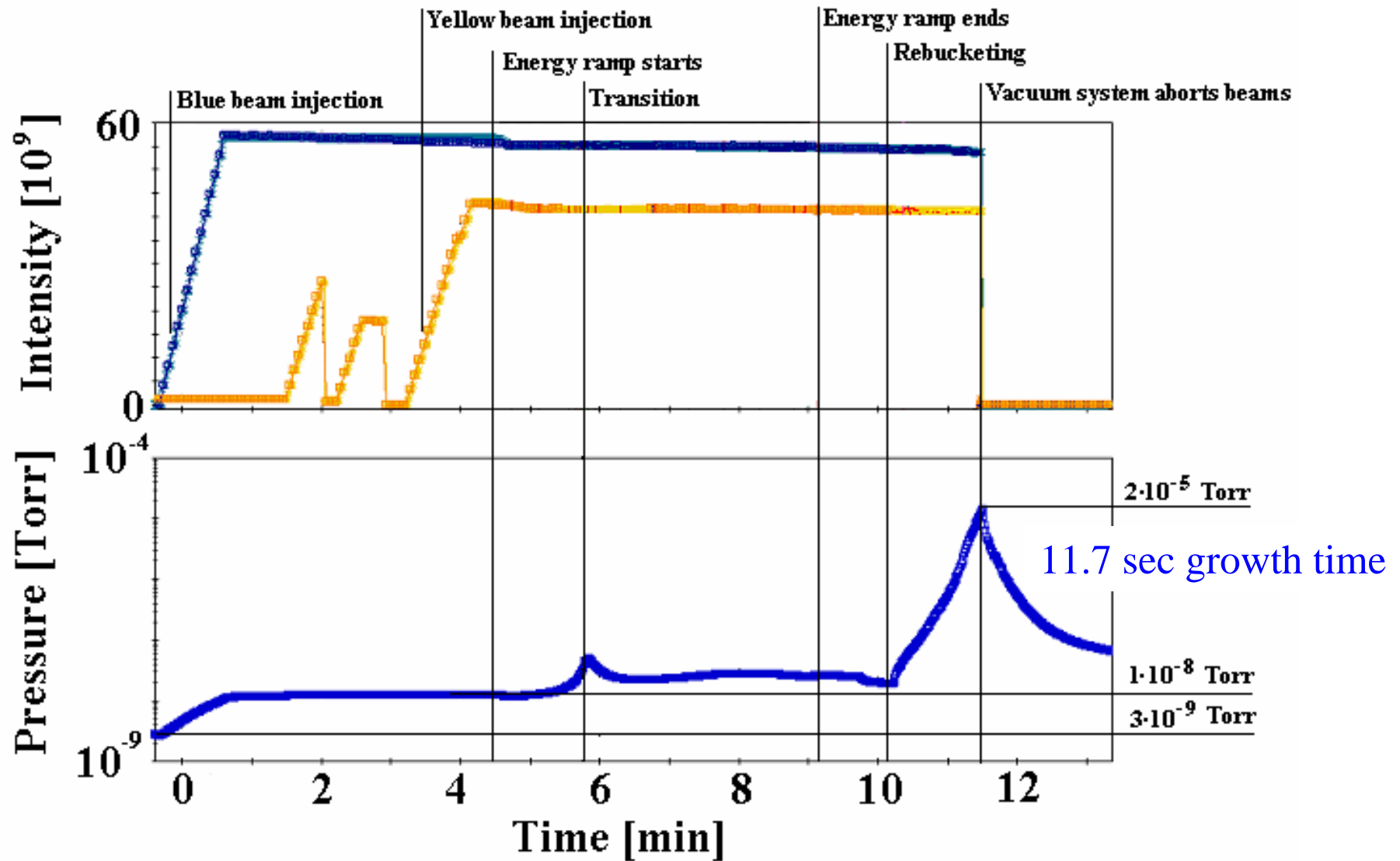
$$E_{\max}=400 \text{ eV and } \delta_{\max}=2.5$$



Center of Be pipe



End of Be pipe



Location of unbaked collimator (unbaked due to scheduling conflict)

- In a number of cases vacuum instabilities were observed (pressure grows exponentially without bound)
- Vacuum instabilities seen
 - Only with Au⁷⁹⁺ beam
 - Only at locations with unbaked surfaces
 - At injection (previous runs)
 - At store, after rebucketing (Run-4)
 - May be at transition
(growth time large compared to transition crossing time)
- Growth times range from 2 to 12 sec

- Need feedback mechanisms for instability
(gas load Q proportional to rest gas pressure P):

- Rest gas ionization by cloud electrons

$$Q_2 = \sigma_e P \frac{2rL}{e} \frac{dI_e}{dl} \eta_{ion}$$

- Rest gas ionization by beam

$$Q_3 = \sigma_b P L \dot{N}_b \eta_{ion}$$

- Define parameter (analog ISR instability)

$$b = \sigma_e \frac{2r}{e} \frac{dI_e}{dl} + \sigma_b \dot{N}$$

e-cloud (20%) beam (80%)
ionization

- Critical desorption coefficient for ionized and accelerated rest gas molecules

$$\eta_{crit,ion} = \frac{\pi^2}{4} \frac{c}{bL^2}$$

c – conductance
 L – half distance
between pumps

- Growth time (very approximate)

$$\tau = \frac{\pi r^2}{b}$$

r – pipe radius

Parameter	Unit	Au ⁷⁹⁺	p ⁺
Reported η_{H_2} [CERN 99-05]	...	0.4	1.5
Reported η_{CO} [CERN 99-05]	...	0.3	1.2
Calc. η_{H_2} critical	...	42	131
Calc. η_{CO} critical	...	2.8	14
Meas. growth time τ	sec	6-12	
Calc. growth time τ_{H_2}	sec	23	
Calc. growth time τ_{CO}	sec	5.4	

- e-clouds contribute about 20% of effect
- Instability may be possible for Au⁷⁹⁺ and CO like molecules.
- Still significant discrepancy between reported η and calc. η_{crit} (higher charge state rest gas ions important?)
- Note: No η measurements available for ion energies below 100 eV.

- In-situ baking of warm elements
($>85\%$ of 700m/ring warm pipes baked)
→ Occasionally installation schedules were too tight
- NEG coated pipes (low SEY, additional pumping)
→ About 250m of NEG coated pipes installed
- Optimized bunch patterns
→ Most uniform along circumference, used this year
- More pumping of before cool-down
→ Need more turbo pumps for full coverage
- Solenoids, scrubbing
→ Tested, no large scale implementation planned near term

- All operational relevant dynamic pressure rises in RHIC can be explained with electron clouds
(abnormal large beam losses can still lead to unacceptable vacuum)
- Electron cloud driven pressure rises observed
 - With all species (Au^{79+} , d^+ , p^+)
 - In warm and cold regions
 - At injection, transition and store
- Pressure instabilities only for Au^{79+} and unbaked wall
(likely caused by rest gas ionization by beam and electron cloud)
- Current counter measures:
 - Complete baking of all elements
 - NEG coated warm beam pipes
 - Optimized bunch patterns
 - Probably pre-pumping of cold sections before cool-down